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UNDERWATER COMMUNICATIONS:
A DISCUSSION WITH TECHNICAL CONSIDERATIONS

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A TECHNICAL REPORT

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INTRODUCTION

Helicopter sea rescue during aircraft carrier flight operations has been extensively investigated. The addition of SCUBA-equipped personnel to this approach obviously enhances any probability for the success of this work, due to the additional time afforded.[1] However, well-coordinated operations using these elements in combination necessitates the consideration of several diverse factors. Fighter aircraft "porpoising" on "take off" present the most stringent ditching and, therefore, rescue problems.[2] Time available for both arrival at rescue scene and actual rescue; plus pilot psychological factors, including reaction and refraction time[3], are but two of these difficulties. Due to these and many other factors, rescue services for aircraft "porpoising" upon take-off from an aircraft carrier will be considered as most important. The information dealing with these rescue activities will, in turn, be fully applicable to any such operations.

In cases where fighter aircraft have "porpoised", there are certain known similarities: the aircraft is fully loaded and, presenting its greatest density, will sink almost immediately. Its sink rate will be high, due to the vehicle's density and low flotation.[4] The vehicle will sink tail first. The pilot, on entry, will be either conscious and able to assist himself, or dead; and, due to the first two factors, time available to perform any rescue operations will be at an absolute minimum. Review of these factors reveals the success of any attempted SCUBA assistance to fighter-aircraft rescue operations depends on the time consumed in getting into action. Hence, any equipment contingent to SCUBA rescue must require minimum or no preparation time for use and be extremely reliable.

Of the tools necessary to expeditiously perform such rescue operations, adequate communications between SCUBA diver and his home vehicle would be the most desirable. This discussion, then, investigates the means by which such communications could feasibly be sustained with minimum preparation and maximum reliability.

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[1] "SCUBA Divers Do Pitch In", Approach, August 1960, pp. 36-38.

[2] Hume, LCDR David M., "Ditching Land Planes", Approach, August 1960, pp. 2-19.

[3] Gottsdanker, Robert, "Reactions to Sequences of Signals", MH Aero Document U-Ed 6108:1959 (AD 235 167).

[4] Sink rate figures for various aircraft have been generated ranging from 3 to 12 feet per second. One firm figure in the literature is 8 feet per second for swept wing jet aircraft ("Underwater Escape", Approach, July 1960, pp. 29).

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SECTION I
THE PROBLEM

Maintaining underwater voice communications during SCUBA rescue activities is a problem of major importance. Many solutions are possible; however, few are feasible.

In the following discussion, equipments, system approaches, and design considerations are made for submarine communications at any depth. Foreseeably, only in rare instances will recovery, retrieval, or rescue be attempted within 15 feet. Compressed air SCUBA descent is not restricted to such depths. "Rebreathing" or "closed circuit" devices, which immediately limit any dive to 33 feet are, therefore, not practical for deep descent[5] and will not be further considered. The final communications system will, nonetheless, be compatible with all SCUBA units.

Adding to this information a knowledge of marine topography, from foreshore to offshore, gives us a diving requirement far exceeding the designated 15 feet. During aircraft rescue in open sea, the inherent ability of SCUBA equipments to perform at depths to 200 feet[6] would allow several minutes of working time not permissable through any other means.

Several schemes have been commercially presented attaining to effective underwater communications for SCUBA equipped divers. Units now being marketed fail in this goal, with reason. Though both technically sound and operable within extremely narrow limits, they fail to provide real voice communications. Between submerged diver and surface, or between divers, the failure of so-called SCUBA communicators lies in an impractical approach to end pieces for use by the diver himself.[7]

In fulfilling the requirements for clear voice transmission, the diver's mouth should not be restricted and breathing noise held to a minimum. Consequently, commercially available designs neglecting these factors have to contend with high ambient breathing noises

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[5] Morgan, Bev, "Diving with Safety", U.S. Diver's Co., 1956, pp. 40-41, 50-53.

[6] The normal limit of Navy SCUBA working dives is usually held to between 130 and 150 feet. This depth is determined at the discretion of the diving officer. Dives to 300 feet are possible but, due to nitrogen narcosis, real work at those depths would be impossible.

[7] Wainwright, Walter N., "Comparison of Hearing Thresholds in Air and in Water", The Journal of the Acoustical Society of America, Vol. 30, No. 11, November 1958, pp. 1025-1029.

and complete loss of high-frequency speech components (fricatives and labial dentals).[8] Therefore, before proceeding with any discussion of actual communications hardware, it is suggested full-face plates, or some other means for freeing the diver's mouth, be investigated. Clean vocal inputs, regardless of the system's sophistication, will determine the operability of any solution, with proper overall system functioning dependent upon this point. Once this has been resolved, actual electronic hardware poses no great difficulty.

Essentially, four basic approaches can be made in submerged-to-surface or submerged-to-submerged transmissions. The first of these is the most available, yet least realistic, and simply consists of having the diver surface each time he wishes to transmit to his base of operations (assumed to be a helicopter for this discussion). Immediately, the major difficulties of this approach can be seen. The possibility of decompression difficulties for the diver, in multiple ascents and descents, is always present;[9] transmissions would be potentially interrupted, as the equipment must shed water prior to transmission in each surfacing action; and, of utmost importance, great time is wasted in ascending and descending. In fact, this last item, "ascent and descent", precludes consideration of this as a plausible solution. With a nominal sink rate of but eight feet per second, it would be impossible for a diver to even consider communications; he simply wouldn't have time.[10]

The second approach has all the availability of the first, yet allows the diver to stay submerged while maintaining full communications with the home vehicle. As prospectively seen, the diver and equipment necessary for his task will be dropped by helicopter at the scene of the operation. Basic among those equipments dropped with a diver in relatively isolated open water would be a float.[11] In such circumstances, this float performs several important tasks. Among these are locator duty for both the diver, below the water's surface, and the helicopter above; a rest- and pickup-station for both the diver and rescued party (or parties); and vehicle for surface-to-air transmission components of the communication system. In this approach, a radio-transmitter,

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[8] Wainwright, Walter N., op. cit., p. 1027.

[9] Navy Standard Air Decompression Tables 1 through 5, Educational Research Report 6-57.

[10] "Underwater Escape", Approach, July 1960, p. 10.

[11] Morgan, Bev, op. cit., p. 10.

microphone/speaker combination, reel of submersible telephone line, and necessary jacking, would be included as integral portions of the float.[12] Once in the water, a head-set and microphone (which the diver would be wearing prior to water entry) could be easily connected to the wire reel on the float, communications verified while the diver was still on the surface, and then the dive proceeded with. On descent, wire from the reel would be fed out automatically to the diver, enabling him to maintain two-way communications with his home vehicle throughout the operation. Should difficulties be encountered by the submerged diver, he could ditch his tanks and equipment (including his telephone cabling) and return to the surface. Communication could then be renewed through the microphone/speaker integral to the float.

This approach offers low cost, availability, and high operating reliability. Its limitations lie in the use of cable. That cable must be used will hinder the diver immeasurably in the presence of weed or other entanglements; restrict him by its length; and impose the constant hazard of being severed. Above all, time requisite to reach the float, complete cable connections, and verify system operation, all prior to diving, would immediately disqualify this approach. Rescue of the pilot takes full precedence; time consumed in preparation immediately defeats this.

The third approach would essentially follow the general configuration of the second, insofar as a float would be used. However, instead of a wire reel combination with its necessary connections and dive limitations, the float would mount a hydrophone/audio amplifier combination in conjunction with the UHF transceiver. Diver carried equipment would include the headset mentioned above, plus a second hydrophone/audio amplifier combination. Communications would be sustained through transmitting raw audio into the water. In this manner, no time is lost in preparation. Jacking and verification are condensed to verification alone (and this is accomplished on descent). The diver, once at the scene of his operation, can go directly to work without worry of entanglement, snagged lines, disrupted communications due to disconnection of his headset, or cable severing. Should more than one diver be working on the same operation, such a system would permit communication between them as well as with the surface. Too, situations demanding the diver ditch his gear would not break contact, as all communi-

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[12] Essentially, the diver's gear would be a redesigned, repackaged form of a presently available commercial unit. This unit, as marketed, however, is completely unusable as it does not consider vocal inputs, quick release jacking, suitable earphones, etc.

cations gear would be integral to his exposure suit. Investigations into this approach have been made which will give us some idea as to its feasibility and/or plausible improvements.[13] In one report dealing with this method of underwater communication (so-called "Buddyphones") in which both "recirculating" ("rebreathing") and conventional SCUBA equipments were used, the "recirculating" SCUBA devices were found more desirable due to their low operating noise (no water discharge of exhausted air creating high level disturbances in the audio spectrum). At the outset of this discussion the inherent limitations of "closed circuit" diving equipment were noted; namely, the maximum depth to which a diver might safely descend --- 33 feet. Although, this scheme seems entirely feasible, the obligation to "rebreathing" SCUBA imposes an unnecessary limitation. On further investigation other objections become obvious. The testing procedure for this method of communication was carried out in a fresh-water pond, the surface condition of which was not mentioned. In addition, the ambient temperature of this pond was from 72° F to 74° F, the maximum depth at which testing was performed was 10 feet, and the maximum communication distance between divers (in a quiet area) was assumed to be fifty yards.

SCUBA communications, as foreseen by this author, will not be confined to calm fresh-water ponds within a limited depth, nor at distances as short as 150 feet. The open sea does not present such near ideal conditions. Audio spectrum losses, should this method be placed in use, would not be tied to the type SCUBA equipment used. Marine acoustic phenomena (backscatter, refraction, ambient noise, bottom absorption, thermoclimatic absorption, etc.)[14] would impose greater losses and distortions than any communications system could afford and still be termed reliable. This approach, with its complete freedom of the diver; the possibility of communication between divers; and an absolute minimum of preparation time would seem to offer much that is desirable. In sight of the technological difficulties and limitations contingent to it, however, this scheme must be seen as a starting point from which a more satisfactory system can be derived.

The fourth approach is that of the diver-float combination, as outlined above; but, instead of a hydrophone/amplifier combination, there would be --- integral to the float ---

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[13] Wainwright, Walter N., op. cit., pp. 1025-1029; and, Hamilton, P. M., "Underwater Hearing Thresholds", The Journal of the Acoustical Society of America, Vol. 29, No. 7, July 1957, pp. 792-794.

[14] See articles on underwater acoustics in bibliography.

a supersonic transducer/transceiver device. The diver, for this system, would have a second supersonic transducer/transceiver unit affixed to his suit. As can be seen from the cursory transmission analysis of pure audio spectrum signals in water, there exist certain unsurmountable technical obstacles. By using a slightly more sophisticated approach, the desirable aspects of the third system can be retained while its difficulties are resolved. This can be accomplished by modulating a supersonic carrier with a compressed audio signal (vocal input) and in doing so immediately take advantage of the low underwater losses imposed on such carriers. Calculable losses for carriers in the 15 to 50 KC range can be expressed by the equation: $a = .033f$ db/K yd; where: a = attenuation and f = frequency in KC.[15] To further minimize underwater acoustic interference, this carrier should be frequency modulated. In this manner such phenomena as backscattering, refraction and ambient sea noises can be circumvented. The distance limitations for pure audio spectrum transmissions, from the above formula, can be seen for this application as non-existent when a high frequency carrier (15 to 50 KC) is used, and thermoclimatic absorption in negligible.

In use, all of the advantages of the third approach come into play. Operational verification will be accomplished as soon as the diver enters the water on his way to the stricken aircraft. There would be no loss of time; and the diver is completely free to work, without regard to entanglement or loss of communications. By using instruments of this nature, not only are communications from submerged diver to surface or aircraft possible, but between any number of submerged divers. The integration of supersonic transducer/transceiver items into the diver's suit (either wet or dry) will permit constant communications to be maintained even though, due to some reason, it would be necessary for the diver to ditch his SCUBA gear while submerged. As opposed to the second example, the diver could ascend in such instances and maintain communication throughout his ascent as well as upon surfacing.

The only seeming disadvantage of this system would appear to be its initial cost. Considerable ground work has been covered in low-frequency underwater communications, transducers (both magnetostrictive and electrostrictive ceramic), miniaturization of constituent components and packaging, yet these elements have never been joined in this context.

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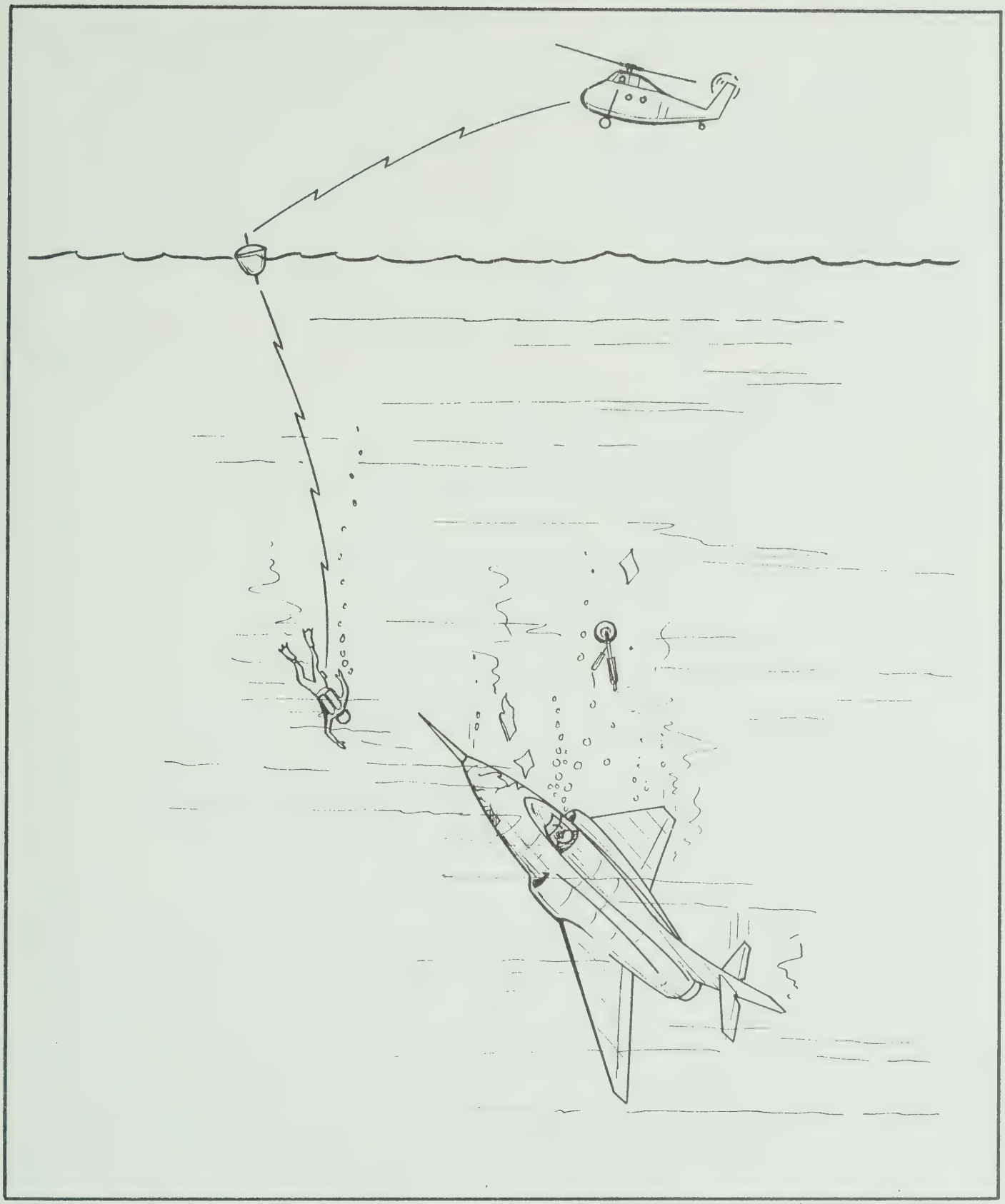
[15] Sheehy, M. J. and Halley, R., "Measurement of the Attenuation of Low-Frequency Underwater Sound", The Journal of the Acoustical Society of America, Vol. 29n4, April 1957.

Advantages of this solution are manifold and include complete freedom of the diver, enabling him to go directly to work, as well as to work in areas of extreme physical congestion (weed, airframe, debris). Reliability, too, is inherent to this solution, since there is no dependence on cabling or other potentially severable connections. And, there is no time consumed in preparation. The diver is ready for descent immediately.

CONCLUSION

In view of the foregoing discussion, the fourth and last approach is recommended. All requirements for submarine-to-surface communications are fulfilled, losses and marine noise phenomena averted, complete mobility of the diver is insured, and absolutely no time is dissipated on communications alone. There are no controls, adjustments or connections to be made by the diver; factors leading to "idiot proof" communications. Logistics, as shown in the following technical discussion, would be restricted to an absolute minimum. Servicing would be held to a remove-and-replace level.

Still another ramification of such a system would be its application to free diving in general (i.e., salvage, ordnance or operational) where genuine voice communications have never really existed.



Underwater Communications: A System

SECTION II
TECHNICAL CONSIDERATIONS

A breakdown of equipments necessary for an underwater communications system, as prescribed in the preceding discussion, gives us three major units: A transceiver for the "home vehicle", the supersonic transceiver for the diver, and the float with integral components for translation and relay. As each presents problems inherent to its particular configuration, these shall be dealt with as individual items in the following.

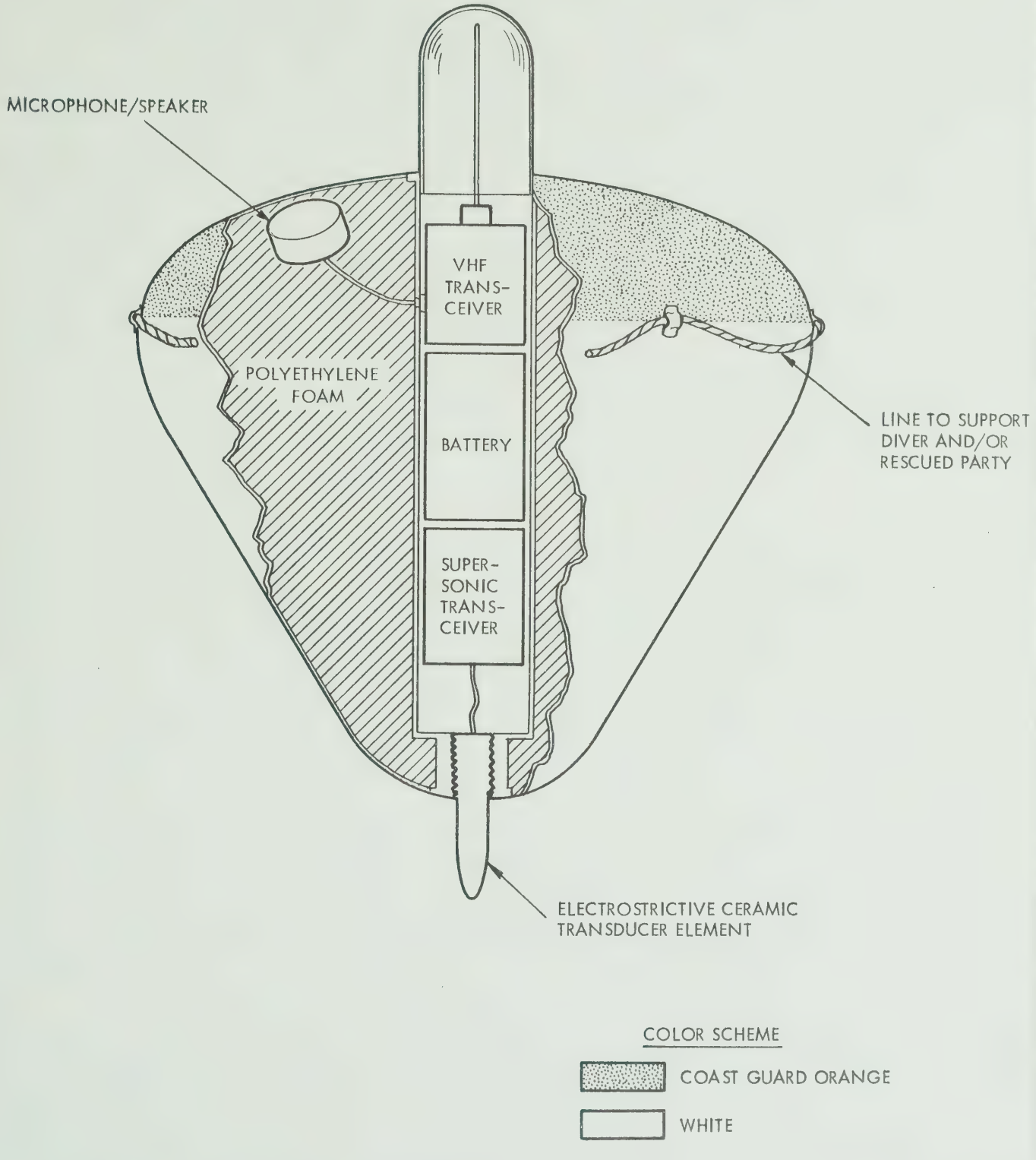
Home Vehicle Transceiver

This instrument will be compatible with either surface or aircraft operation and consists of a VHF Transceiver, all necessary cabling, end pieces and antenna components. Its operation will be straightforward and, once brought into play, can be monitored with existing radio nets in the area. Operating frequency allocation for this system will be made prior to delivery. Packaging for this unit, as presently conceived, will follow the latest advances permitting an optimized use of semiconductors, modular circuit construction, and encapsulation. Repair of these units, taking advantage of high production standardization, circuit boards and modular assembly, would merely consist of removal and replacement. "Home vehicle" installations, miniaturization and construction, will require minimum weight and space, as well as afford extremely flexible mounting. Existing communications equipment might also be used for "home vehicle" gear. The only considerations necessary for their use would be type of modulation and operating frequencies. These system aspects could readily be incorporated into the float VHF Transceiver with minimum difficulty.

Float

As previously described, this unit will not only act as a vehicle for VHF transceiver and supersonic transceiver/transducer, it will serve two utilitarian functions: that of locator device for both the diver and home vehicle, and rest point for the diver and rescued party (or parties) brought to the surface. The float would be constructed of polyethylene foam, sealed and colored for maximum visibility.[16] Communications equipments consituting this portion of the system would be housed in a watertight plastic capsule and mounted in the float's center. The float would be designed to right itself upon water entry, and offer sufficient buoyancy for several men who could potentially cling to its edge. The transdu-

[16] Coast Guard orange on the top and white on the bottom, are recommended for this purpose.



Underwater Communications System Float

cer would be affixed to the float's bottom for maximum efficiency. The VHF antenna would be contained in a non-interfering plastic bubble on the top, to avoid salt contamination of this element during operation in any weather. All constituent electronic components would be transistorized and potted.

To power this instrument, there would be an integral rechargeable battery, fully charged at all times. As a precaution against possible failure of the underwater supersonic link, a combination microphone/speaker would be built into the float permitting communications from the surface. This microphone/speaker combination would also act as a psychological aid to any rescued parties in again being able to contact their fellows.[17] Submarine operation frequencies would lie between 15 and 50 KC, as this "band" would appear ideal for this application.[18] To avoid the introduction of ocean noise phenomena into this intelligence, the carrier will be frequency modulated. Voice modulation, both at the float and the diver's instrument, would be held to a 2.25 KC spread between 250 and 2,500 CPS, permitting full advantage of low-frequency underwater transmission.[19] Should other units be used, necessitating different frequencies, ample bands would be available without loss of efficiency or interference.

Diver's Supersonic Transceiver

This instrument, affixed to the diver's suit, will be miniaturized, fully encapsulated and consist of but two units (the supersonic transceiver/transducer and a head set). Since communications from this item will be maintained underwater, it is suggested the transceiver be attached to the diver's leg by means of a pocket in his exposure suit. Necessary cabling can be made on the inside of the suit for subsequent connection to the head set. As in the "home vehicle" unit, both weight and space would be held to a minimum. There are two reasons for attachment of this instrument to the diver's leg.

First, in this position it would offer least hindrance to the diver's mobility. Due to its lightweight (perhaps slightly negative buoyant) and small size, it would pose no problem and would not be in the diver's way. Too, in this position the diver could ditch his gear (tanks, weight belt and sundry equipment) and still continue transmissions to the "home vehicle".

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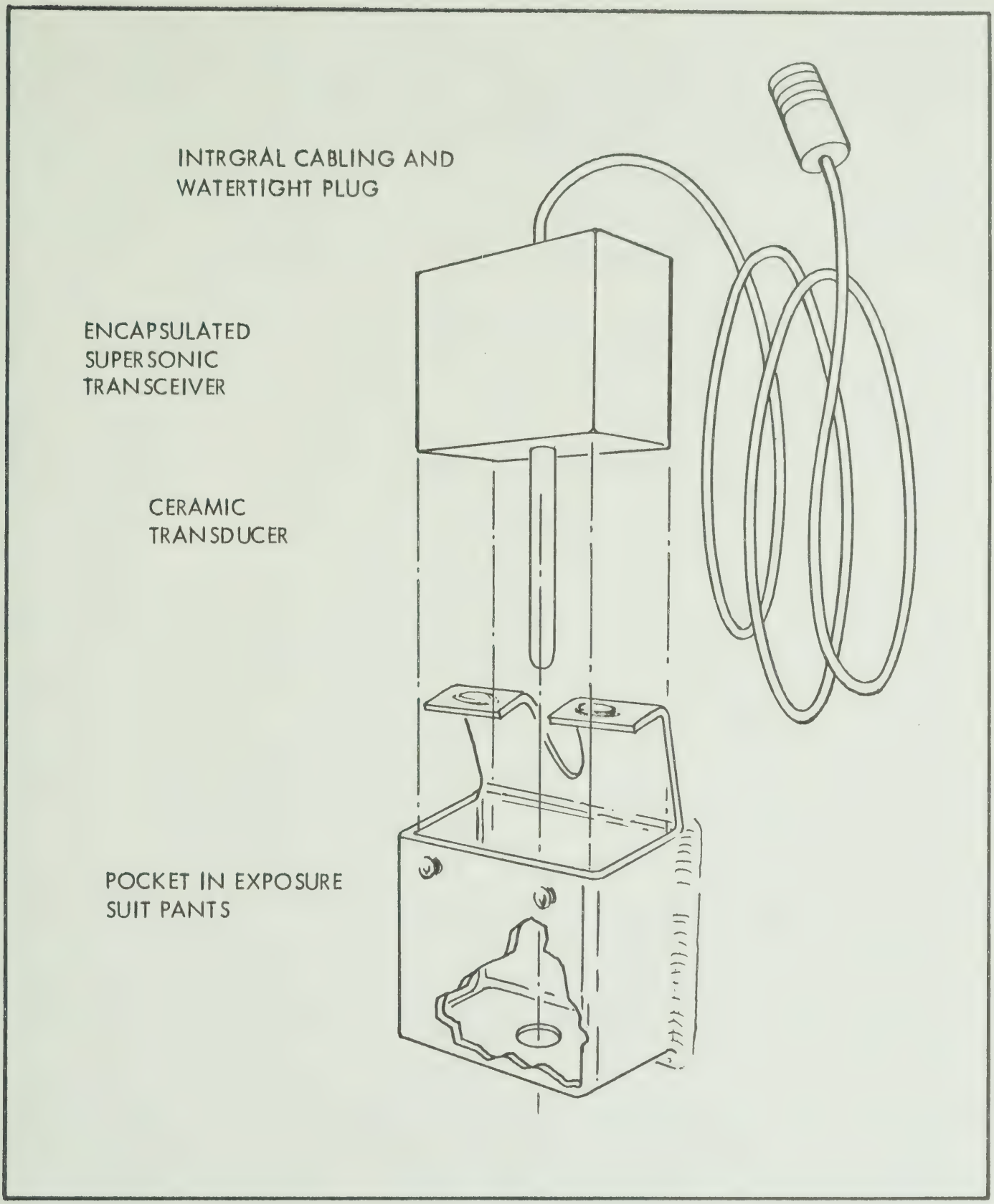
[17] Psychological aspects of mild traumatic depression would point up the desirability of such a feature.

[18] Sheehy, M. J., op. cit.

[19] Isaak, R. D., "Underwater Communication", The Journal of the Acoustical Society of America, Vol. 28n4, p. 556, July 1956.



Diver's Supersonic Transceiver

The second reason lies in the mode of radiation. To sustain supersonic underwater communications of an omnidirectional nature, the transducer unit should be submerged for reasonable effectivity. Should this instrument be mounted on the diver's back or belt, as the diver neared or was on the surface, communications would suffer. By placing the transducer and transmission components of this system at a point on the diver which --- at no time during operations after water entry --- will break the surface, communications will be secured.

Supersonic Transceiver

This instrument will consist of fully encapsulated circuitry with integral transducer. The transducer element suggested for this application will be a ceramic electrostrictive unit (barium titante).[20] Ceramic electrostrictive transducers are not only easily manufactured to any physical configuration and rugged enough to withstand the impact of water entry, but are small enough (in the suggested frequency band) not to impede the diver in his work. Piezo Electric crystal transducers, on the other hand, become complex units, ungainly in size and somewhat delicate for this application.[21] The circuitry will be transistorized, fully potted and have an integral battery. There are potentially three battery types available for this task: rechargeable alkali; disposable mercury; and salt water activated. For this particular application where operations may not be in salt water, the disposable mercury battery appears to be most desirable. The entire instrument will be ready for operation at all times, and connected into the diver's suit prior to his being carried aloft by the helicopter. The frequency of operation will be preset as determined by the operating frequency of the float. Cable will be integral to the transducer/transceiver and will be mated to the head set via watertight connector. There will be no operating controls as such, on this instrument. Connecting the headset cable will activate the receiver section while the transmitter portion will be voice controlled.

Diver's Head Set

The head set will consist of two waterproofed components: an earphone and a throat microphone. The earphone will be of the bone contacting type to minimize the impedance losses inherent in conventional units.[22] The microphone would be of the throat type, and therefore not requiring connection to the diver's faceplate. The entire head set poses no

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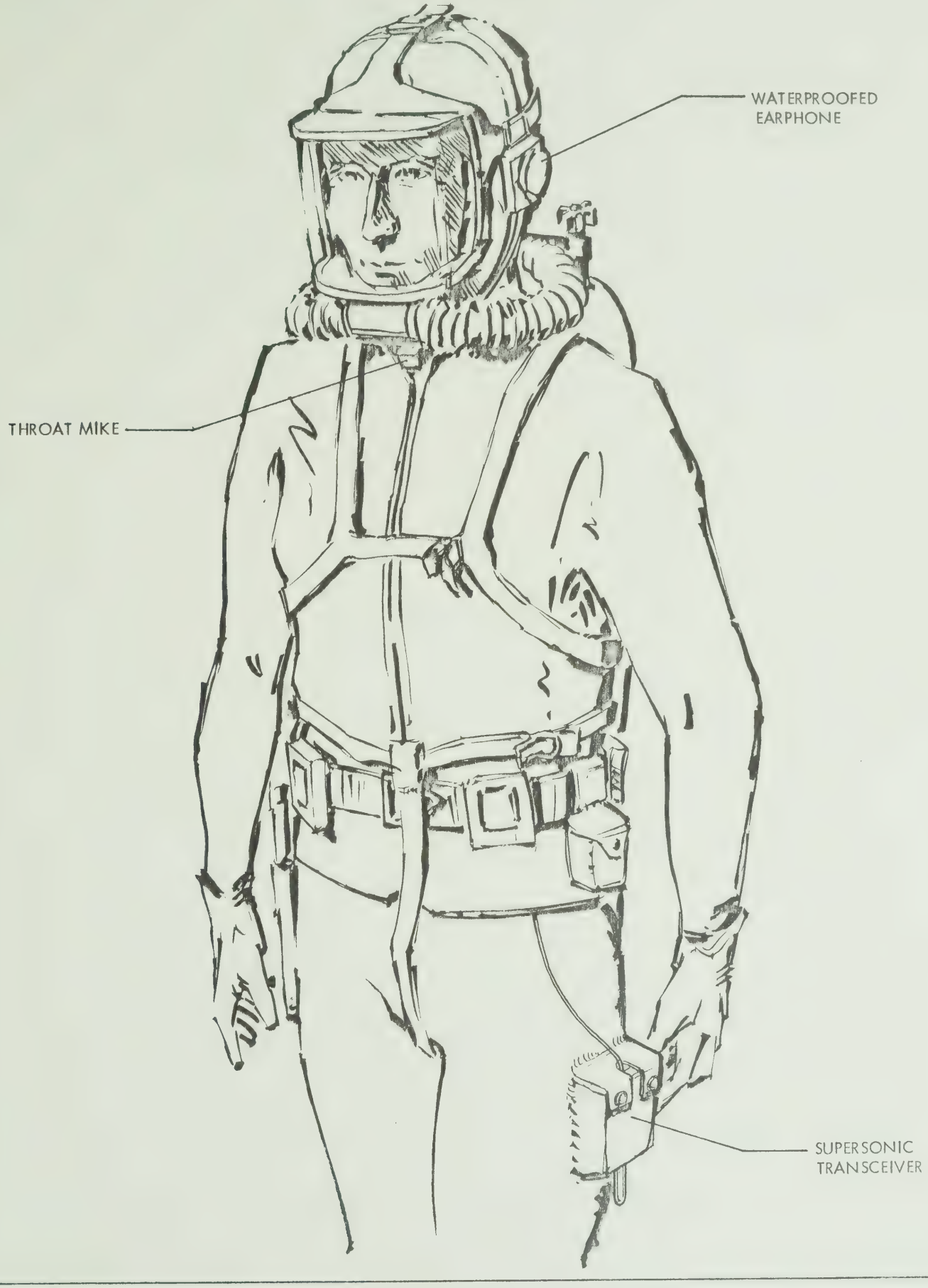
[20] Rand, George, "Sonar and the Fourth Dimension", Sperry Engineering Review, VII, pp. 6-9, October 1958.

[21] The USRL Type E8 Transducer --- An Underwater Sound Calibration Standard for the 100-1000 Kilocycle Frequency Range. Underwater Sound Reference Laboratory Report No. 22, June 1952.

[22] Ide, Dr. John M., Signalling and Homing by Underwater Sound; For Small Craft and Commando Swimmers. Naval Research Laboratory Sound Report No. 19, June 1944.

availability problem as it consists of standard items throughout. Connection to the head set will be made after the diver is in his suit through watertight jacking and will effectively energize the transceiver. As headset weight, size and location will not hinder the diver --- nor present ditching difficulties, this jacking need not be "quick release".

These diver's instruments would be operable at all times, regardless of water position. Should two or more divers be operating in the same area, these units would be fully compatible with each other and permit communications between divers as well as with the surface. In such instances, only one float would be necessary, as satellite supersonic instruments would be operated on the same frequency. Should several such rescue groups be working in the same vicinity, and confusion result from numerous links being operated on one frequency, then separate bands could be provided to isolate these groups from one another. Each supersonic frequency used would necessitate another float, not only for operating frequency allotment, but as a safeguard for sustained transmissions, as each float would be in the immediate area of the divers using that particular frequency, minimizing the distance (and potential disturbance of communications) between diver and float.



SCUBA Diver Equipped for Underwater Communications

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